

Better Buildings Residential Network Peer Exchange Call Series:

We Love Our National Labs: Research Results Part 2 February 28, 2019



Agenda and Ground Rules

- Agenda Review and Ground Rules
- Opening Poll
- Residential Network Overview and Upcoming Call Schedule
- Featured Speakers:
 - Bo Shen, Oak Ridge National Laboratory
 - Cheryn Metzger, Pacific Northwest National Laboratory
 - Eric Wilson, National Renewable Energy Laboratory
- Open Discussion
- Closing Poll and Announcements

Ground Rules:

- 1. Sales of services and commercial messages are not appropriate during Peer Exchange Calls.
- 2. Calls are a safe place for discussion; **please do not attribute information to individuals** on the call.

The views expressed by speakers are their own, and do not reflect those of the Dept. of Energy.





Better Buildings Residential Network

Join the Network

Member Benefits:

- Recognition in media and publications
- Speaking opportunities
- Updates on latest trends
- Voluntary member initiatives
- Solution Center guided tours

Commitment:

Members only need to provide one number: their organization's number of residential energy upgrades per year, or equivalent.

Upcoming calls:

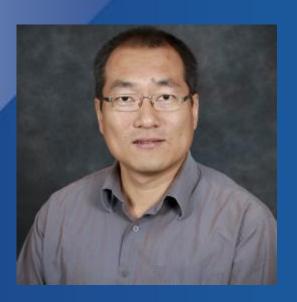
- March 14th: Efficiency and Resilience Improvements with PACE Financing
- March 28th: The Next Frontier: Energy Storage and Batteries
- April 11^{th:} What's Keeping Energy Experts Up at Night? Technical Problems
 That Need to Be Solved

Peer Exchange Call summaries are posted on the Better Buildings website a few weeks after the call

For more information or to join, for no cost, email bbresidentialnetwork@ee.doe.gov, or go to energy.gov/eere/bbrn & click Join







Bo Shen, PhD
Oak Ridge National Laboratory





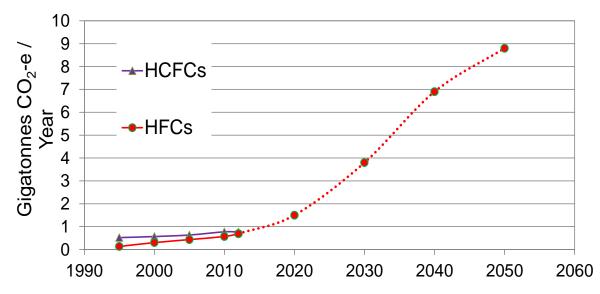


ORNL is managed by UT-Battelle, LLC for the US Department of Energy



Next generation low GWP refrigerants are coming

US and world are moving towards next generation refrigerants. National labs need to go ahead of the game and provide a public-domain knowledgebase.





Developing countries (China, India, etc.) catch up quickly

Global emissions of fluorocarbon refrigerants

http://www.esrl.noaa.gov/csd/assessments/ozone/2014/assessment_for_decision-makers.pdf http://www.atmos-chem-phys.net/14/4563/2014/acp-14-4563-2014.pdf

Next generation refrigerants can contribute to 25% reduction of GHG. Leadership in this transition will greatly boost export and create thousands of jobs.



US chemical manufacturers leading the next generation refrigerants

R-22 (HCFC) alternatives (HFO blends)

Refrigerant	Manufacturer	GWP
R-22	-	1,810
N-20b	Honeywell	988
R-444B	Honeywell	295
DR-93	Chemours	1,258
R-454A	Chemours	239
DR-3	Chemours	148

Hydrofluoroolefins (HFOs)
Fluorinated propene
isomers
R-1234yf (CF3CF = CH2)
R-1234ze (CF3CH = CHF)
GWP < 4
Mildly flammable

R-410A (HFC) alternatives (HFO blends)

Refrigerant	Manufacturer	GWP
R-410A	-	2088
R-447A	Honeywell	583
R-447B	Honeywell	740
R-452B	Chemours	698
R-454B	Chemours	466

Next generation refrigerants can result in > 70% GHG reduction with better energy efficiency than HFC and HCFC → US OEMs have to design and use them right !!!

Objectives

Provide a public-domain knowledgebase to accelerate transition to next generation refrigerants and maintain US industry's leading position – built upon a well-regarded vapor compression system modelling framework, DOE/ORNL Heat Pump Design Model (HPDM) (https://hpdmflex.ornl.gov/)

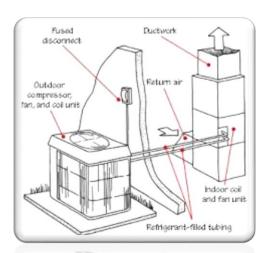
- Support technicians: ORNL Fingertip Fluid Properties (fProps) -a mobile phone app that allows HVAC technicians to quickly check fluid properties before equipment installation or repair.
- Support equipment design engineers: upgraded HPDM (HPDMFlex) - assist US engineers to design and optimize HVAC equipment using new refrigerants in wide categories having hundreds of configurations.



ORNL HPDM Serves US Industry Since 1970- extensive applications and complex system configurations in HVAC&R



Refrigerator



Heat pump



Water heating



Rooftop Air conditioner

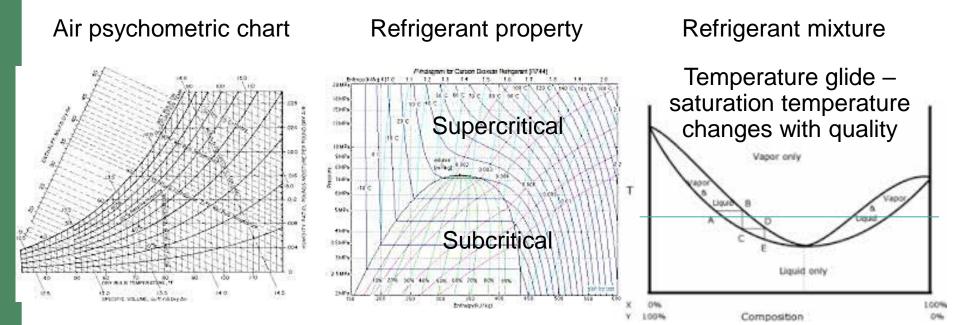


Complex System Configurations



Universal working fluid property management

-Hundreds of working substances in HVAC&R industry: air, water, glycol, CO2, HFC, HCFC, CFC, HFO, natural substances



Next Generation Refrigerants (low global warming - GWP, zero ozone depletion) – detailed system modeling with new refrigerant property, to assess long-term impact using life cycle analysis, provide design guidance based on fundamental study.



Demo – Mobile tool: ORNL Fingertip Fluid Properties (fProps); https://hpdmflex.ornl.gov/fProp/wizard/welcome.php





DOE/ORNL Fingertip Fluid Properties (fProps)

Welcome to the Fingertip Fluid Properties (fProps) on the web

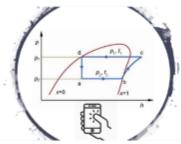
This vehicle provides five fluid properties, easily accessible using your iPhone or other mobile devices, i.e. fingestips, with an INTERNET connection. It includes properties of psychrometric (air), coolant (water and glycols), refingerants, and capacity calculation functions. It aims to support technicisms and engineers to have a quick check of these properties when they work in the field. for example, installing a HVMC equipment. The main driver is to accelerate transition from conventional refrigerants having high global warming potential (GWP) to new low GWP refringerants, to support professionally using these new refringerants.

The user can specify the inputs of each property calculation module. An example case is provided for each individual module.

The wizard will guide you through the use of the property modules. The wizard includes remerous property modules in multiple categories. You are more than welcome to work with us and create other new modules or categories for your interest. If you have suggestions or find any bugs related to this property calculations tool, please contact the suther, Bo Shen, sheab@goml.gov.

Below, you can either expand a category by clicking the triangle on the left, select an existing module and make your inputs (Customize Configuration).

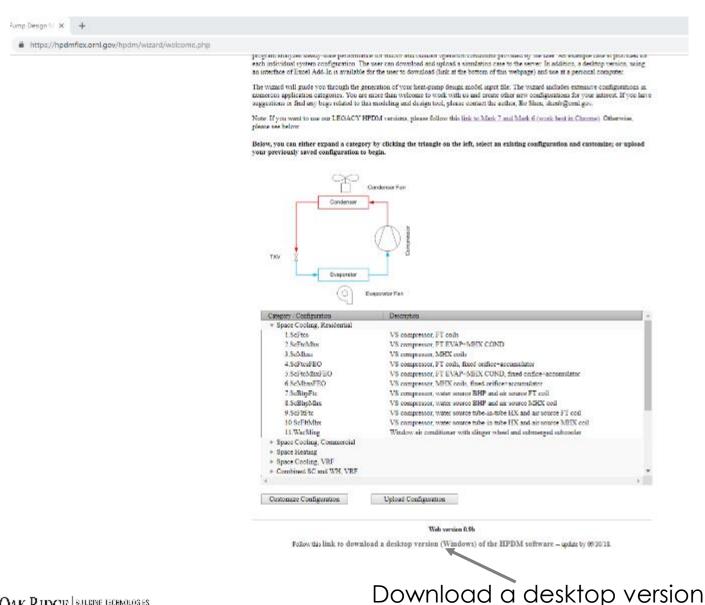
Step-by-Step: Select a calculation module. >Click "Customize Configuration". >Select seftigerant type if refrigerant property is needed. >Click "Next". >Edit imput» > Click "Next". >Click "Run". >See results.



Category / Configuration	Description
* Refrigerant Properties	
1.PtoDew	Calculate dew point temperature at given pressure
2.PtoBubble	Calculate bubble point temperature at given pressure
3.DewtoP	Calculate pressure at given dew point temperature
4.BubbletoP	Calculate pressure at given bubble point temperature
5.PTtoSuperheat	Calculate superheat degree at given pressure and temperature
6.PTtoSubcool	Calculate subcooling degree at given pressure and temperature
7.TSuptoP	Calculate pressure at given temperature and superheat degree
8.TSubtoP	Calculate pressure at given temperature and subcooling degree
9.PSuptoT	Calculate temperature at given pressure and superheat degree
10.PSubtoT	Calculate temperature at given pressure and subcooling degree



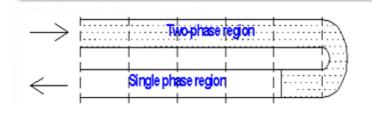
Demo – Online Design Base: ORNL Heat Pump Design Model https://hpdmflex.ornl.gov/fProp/wizard/welcome.php

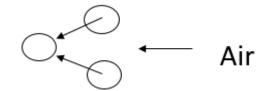




Arbitrary HX Circuitry - Segmented Fin-&-Tube Coil modeling to reoptimize heat exchanger configurations

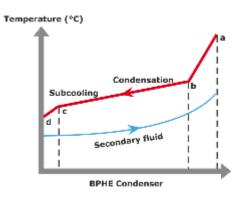
2-D air side distribution; Independent circuit refrigerant entering conditions; Arbitrary circuitry, provides more accurate real-world heat exchanger performance predictions

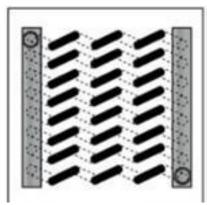


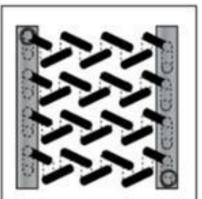


		1	1	
Refrigerant	Glide in	Glide in	Critical	Vendor
	Condenser	Evaporator	Temperature	
	[K]	[K]	[C]	
R-22 (baseline)	0.0	0.0	96.16	N/A
R-444B	7.6	8.9	92.11	Honeywell
R-454A	5.4	6.2	78.94	Chemours

Some HFO blends have significant glides (difference between dew and bubble temperatures) → Heat exchanger configurations have to be reoptimized.







Key Points

- ORNL has developed an easy online tool to help HVAC engineers and technicians transition to the next generation of refrigerants.
- The associated knowledge base will accelerate this transition, and maintain US industry's leading position.
- View a demonstration of the mobile tool (ORNL Fingertip Fluid Properties) <u>here</u>.







Cheryn Metzger
Pacific Northwest National Laboratory

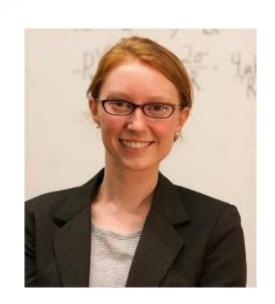




Large Scale Load Shifting with Heat Pump Water Heaters

CHERYN METZGER

We Love Our National Labs: Research Results Part 2



Co-Authors/Team Members



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Walt Hunt, PNNL

Project Goals



- Compare data reported from the universal communication modules to sub-metered data to determine accuracy.
- Determine the kW reduction (on-peak) between electric resistance (ERWHs) and connected heat pump water heaters (HPWHs);
- Demonstrate a 24x7 control paradigm for shifting load to align with renewable generation (e.g., evening load shifting toward later in the night when wind energy would be more prevalent);
- Evaluate customer acceptance/impact of 24x7 demand response operation of their water heater; and





Background: CTA-2045



- The original manufacturer needs to provide only the standard port (not the additional hardware).
- Any number of stakeholders (e.g. utilities) can pay for the additional "connected" hardware required to turn an unconnected appliance into a connected appliance;
- ► The modular interface supports every type of communication method at the physical layer (e.g. Wi-Fi, 4G LTE, etc.) and at the command layer (e.g. SEP, OpenADR, etc.); and
- A third party can manufacture the connected hardware.



High Level Project Overview



- Scope
 - ~145 HPWH using CTA2045
 - ~86 Electric Resistance WH using CTA2045
 - ~2 load shifting events per day during peak hours
 - ~10 weeks of data
- Roles and Responsibilities
 - BPA: Primary funder and high level management of study
 - DOE: Funder of PNNL work
 - PGE: Lead utility, CTA-2045 event implementer
 - Other Utilities: Recruitment of homes for study
 - NEEA: Market analysis
 - PNNL: Analysis and reporting

Minute Data Being Collected Through CTA2045 Portal



Label	Description
CTA-2045	Operational State
Operating State	Running, idle, running in a cycle mode
Curtail Type	None, shed, grid emergency, start autonomous cycling, request power level, load up, CEA-2045 error, customer override, end shed, terminate autonomous cycling
Curtailment message %	% of time the system was on during the curtailment event
Current Watts	Instantaneous watts
Total Wh	Total energy storage Wh

Sub-Meter Comparison to CTA-2045

- Using RX3000 data loggers
- Measurements:
 - Room ambient temp
 - Hot water pipe surface temp
 - 1 minute current (amps) to the tank
 - On day of logger installation
 - 5 minutes of true kW, A, V and PF (Dent Elite) in heating mode

Needed to make adjustments for one manufacturer

Mode	Reported by CTA-2045 Port	Sub-Metered
Heat Pump Only	800	368
Electric Resistance Only	4500	4140
HP + ER	5300	4505



Data and Photo Courtesy of Nathan Kelly, BPA

Example Event Schedules



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Date	Event Description	Duration	Start Time	End Time	
Feb. 19 th	Load Up	1 hr	5:00	5:58	
Feb. 19 th	Shed	3 hrs	6:00	9:02	
Feb. 19 th	Load Up	1 hr	16:00	16:58	
Feb. 19 th	Shed	3 hrs	17:00	20:02	
Feb. 20 th	Same daily events as	Feb. 19 th			
Feb. 21 st	Same daily events as Feb. 19 th				
Feb. 22 nd	Load Up	1 hr	6:00	6:58	
Feb. 22 nd	Shed	2 hrs	7:00	9:00	
Feb. 22 nd	Load Up	1 hr	14:00	14:58	
Feb. 22 nd	Shed	2 hrs	15:00	17:00	
Feb. 22 nd	Load Up	1 hr	22:00	22:58	
Feb. 22 nd	Shed	2 hrs	23:00	1:00	
Feb. 23 rd	Same daily events as Feb. 22 nd				
Feb. 24 th	Same daily events as Feb. 22 nd				
Feb. 25 th	Same daily events as Feb. 22 nd				

Load Up Event = Force WH to turn on and reach highest point of set point dead band

Shed Event = Force WH to turn off as long as customer still has hot water (exact definition of "hot water" is determined by manufacturer/algorithm)



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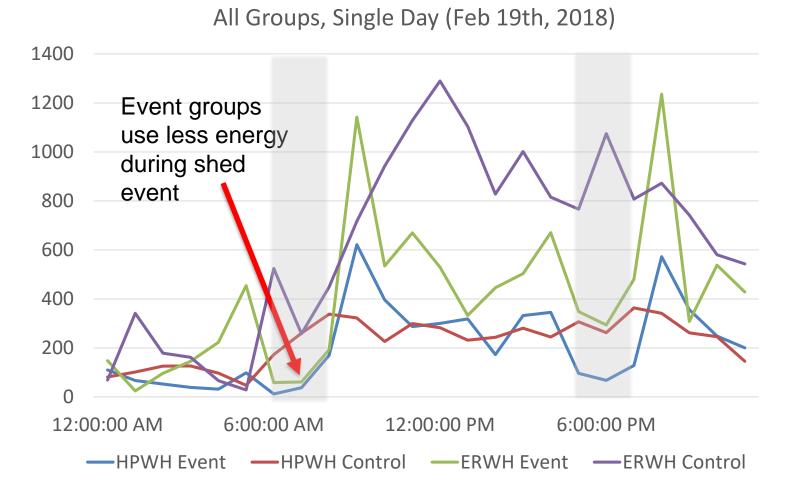
General Trends



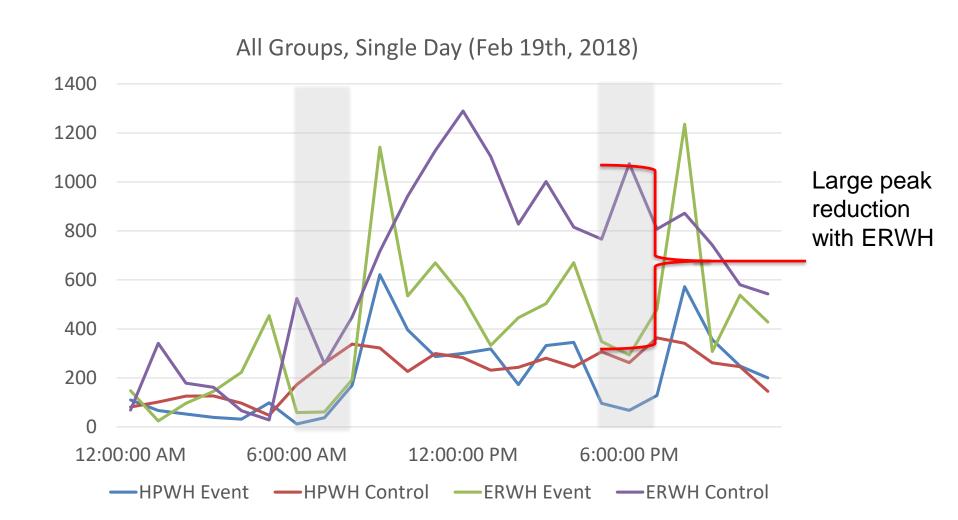
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Low energy use by all groups at night All Groups, Single Day (Feb 19th, 2018) 1400 1200 1000 800 600 400 200 12:00:00 AM 6:00:00 AM 12:00:00 PM 6:00:00 PM —HPWH Event —HPWH Control —ERWH Event —ERWH Control



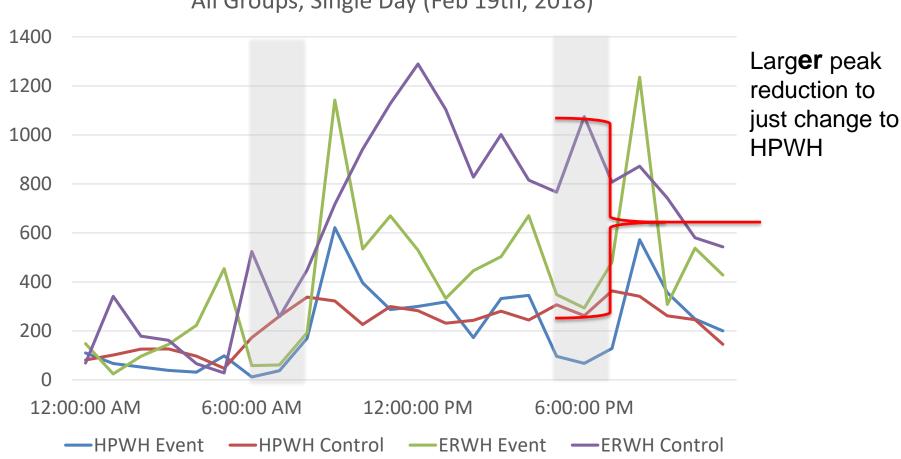




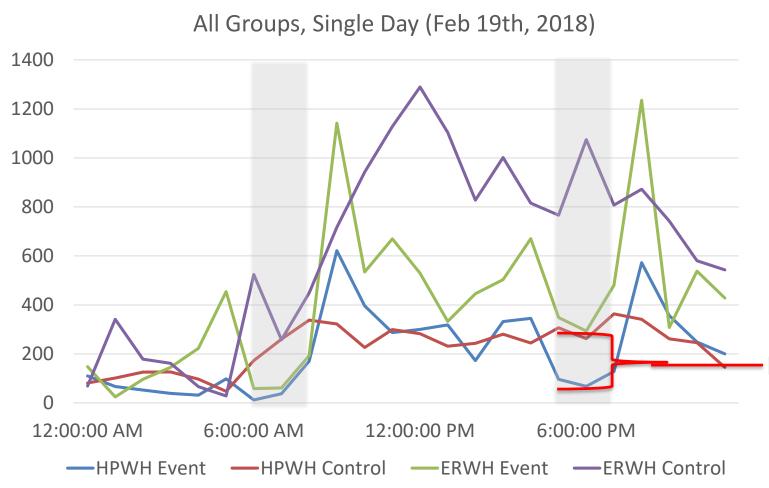




All Groups, Single Day (Feb 19th, 2018)







Measurable peak reduction with HPWHs

Coldest-Days Load Reduction Savings Using Shed Command



Average of Coldest Winter Days (Feb 19th, 20th, 21st, 26th, 27th, March 2nd, 8th, 9th, 14th and 15th, 2018)

Peak Load Reduction	ER Control (W/Hour of DR Event)	ER Control – ER with DR (W/Hour of DR Event)	ER Control – HPWH Control (W/Hour of DR Event)	ER Control – HPWH with DR (W/Hour of DR Event)	% Savings for Switching to HPWH with DR (W)
Morning Peak	623	381	329	540	87%
95% CI for Morning Peak	85	79	83	84	N/A
Evening Peak	668	320	442	602	90%
95% CI for Evening Peak	57	77	65	58	N/A

~90% of the daily peak load can be eliminated by just switching from ERWHS to Connected HPWHS



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Determining Average kW Reduction

Relevant Information



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"Winter" Season

► January 22nd to April 1st, 2018

Grouped by Time of Day

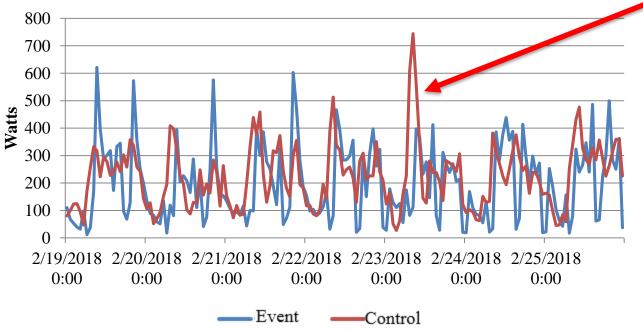
- 10pm to 5am
- 6am to 10am (morning peak)
- 11am to 4pm
- 5pm to 9pm (evening peak)

Average kW Reduction During Shed Events (For each water heater type)



- Many ways to determine the average kW reduction
 - Baseline 1: Event Group vs. Control Group





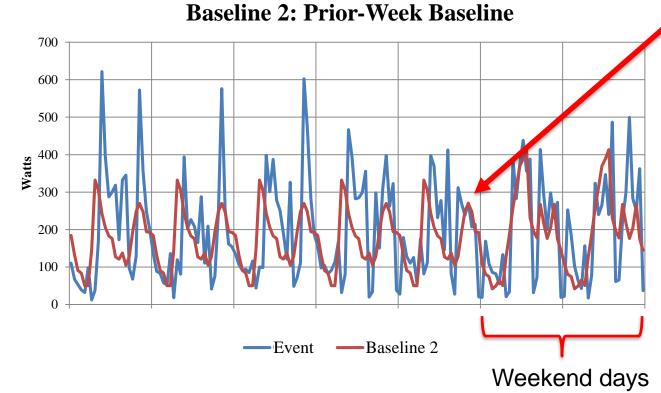
Unpredictable behavior is expected in this baseline

- Baseline 2: Prior- Week Baseline
- Baseline 3: Full Season Baseline

Average kW Reduction During Shed Events (For each water heater type)



- Many ways to determine the average kW reduction
 - Baseline 1: Event Group vs. Control Group
 - Baseline 2: Prior- Week Baseline



Unpredictable behavior is averaged out in this baseline

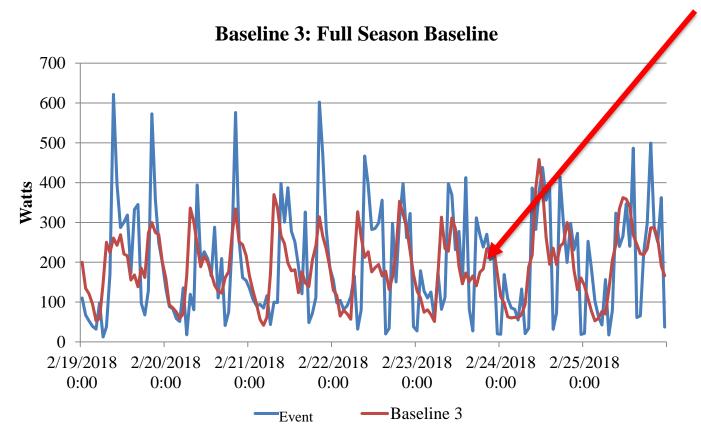
Baseline 3: Full Season Baseline

Average kW Reduction During Shed Events (For each water heater type)



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- Many ways to determine the average kW reduction
 - Baseline 1: Event Group vs. Control Group
 - Baseline 2: Prior- Week Baseline
 - Baseline 3: Full Season Baseline



Baseline 3 trends toward a typical hot water load profile

kW Reduction Using All Shed Events



	Heat Pump Water Heaters (n=145)			Electric Resistance (n=86)		
Baseline #	Base 1	Base 2	Base 3	Base 1	Base 2	Base 3
Average Impact from 10pm to 5am	84	95	84	133	146	194
Std. Dev. ¹ from 10pm to 5am	34	25	N/A ²	81	59	N/A
Average Impact from 6am to 10am	201	196	232	337	318	444
Std. Dev. from 6am to 10am	45	45	N/A	67	121	N/A
Average Impact from 11am to 4pm	170	148	N/A ³	322	329	N/A
Std. Dev. from 11am to 4pm	47	29	N/A	114	133	N/A
Average Impact from 5pm to 9pm	142	161	167	328	312	316
Std. Dev. from 5pm to 9pm	47	46	N/A	85	99	N/A

- 1. Standard deviation provides information about the variation of the average impact between the 10 weeks studied in the season
- 2. Only the last week of the season is part of this event group
- 3. No events occurred during this time for the week of March 26th

Coldest-Days Load Reduction Savings Using Shed Command



Thum, operated black and the second of the s

Average of Coldest Winter Days (Feb 19th, 20th, 21st, 26th, 27th, March 2nd, 8th, 9th, 14th and 15th, 2018)

	Heat Pump Water Heaters (n=145)		Electric Resistance (n=86)	
	Baseline 1	Baseline 2	Baseline 1	Baseline 2
Morning Peak Load Reduction Using Shed (W)	211	235	381	366
95% CI for Morning Peak	25	29	79	52
Evening Peak Load Reduction Using Shed (W)	160	171	320	321
95% CI for Evening Peak	37	26	77	72



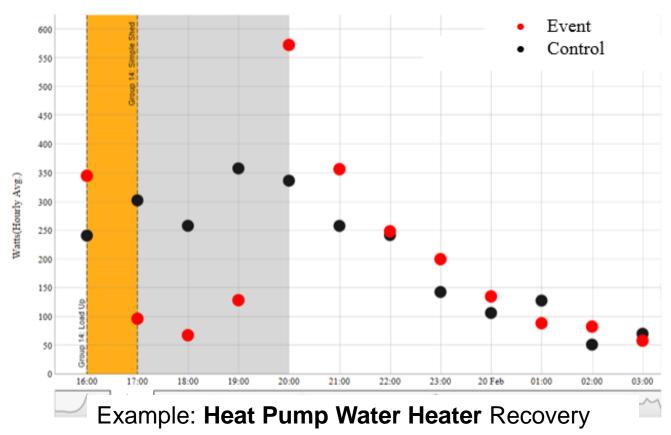
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Recovery Energy

Recovery Time/Energy: HPWH



- Challenges
 - Unknown recovery energy associated with draws during shed period
 - Unknown recovery energy associated with draws during recovery period



Orange Region Represents the Load Up Period, Grey Region Represents the Shed Period

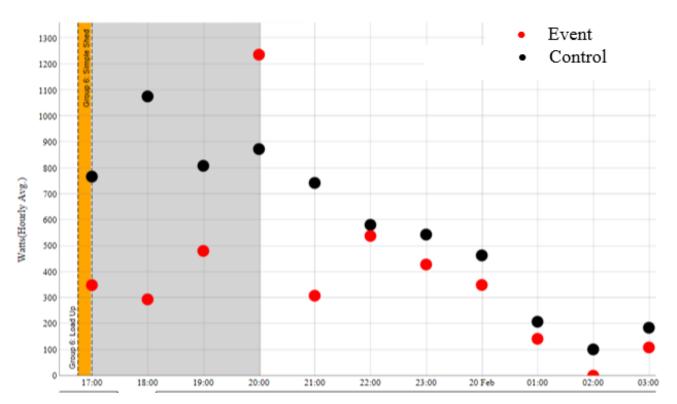
Recovery Time/Energy: ERWH



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Challenges

- Unknown recovery energy associated with draws during shed period
- Unknown recovery energy associated with draws during recovery period



Example: Electric Resistance Water Heater Recovery

Orange Region Represents the Load Up Period, Grey Region Represents the Shed Period

Customer Acceptance



- 1634 opt-out hours during the winter season
- Out of 40,000 opportunities to opt-out (145 customers, about 28 event-hours per week)
- Results in 4% opt-outs (relatively low!)
- Most customers seem largely unaffected by the demand response program

Reminder: Project Goals



- Compare data reported from the universal communication modules to sub-metered data to determine accuracy.
- Determine the kW reduction (on-peak) between electric resistance (ERWHs) and connected heat pump water heaters (HPWHs);
- Demonstrate a 24x7 control paradigm for shifting load to align with renewable generation (e.g., evening load shifting toward later in the night when wind energy would be more prevalent);
- Evaluate customer acceptance/impact of 24x7 demand response operation of their water heater; and





Conclusions Related to Project Goals



- Some manufactures are reporting constant numbers for HPWHs in various modes, when actual energy is variable
- kW reduction on the coldest days, during peak times
 - ERWH Control HPWH Event: kW reduction ~540-600 W per hour of shed event
 - HPWH Control HPWH Event: kW reduction ~160-240 W per hour of shed event
 - ERWH Control ERWH Event: kW reduction ~320-380 W per hour of shed event
- Demonstrated a 24x7 control paradigm for shifting load to align with renewable generation
- Customer acceptance around 96%



- ▶ BPA-Driven Project
 - 10-year market deployment strategy
 - More utility investment
- PNNL Technical Scope
 - Transferred management of DR events to PNNL
 - More consistent cold winter data
 - Finer grouping strategy



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Thank you!

CHERYN METZGER, PE, PMP, LEED AP

Pacific Northwest National Laboratory

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Key Points

- Leveraging heat pump water heaters and smart monitoring devices together offers great potential for energy savings and load reduction.
- PNNL conducted research seeking to, among other things, demonstrate a 24/7 control paradigm for shifting load to align with renewable power generation.
- Results were promising, with very high customer acceptance. Next steps include developing a market deployment strategy.







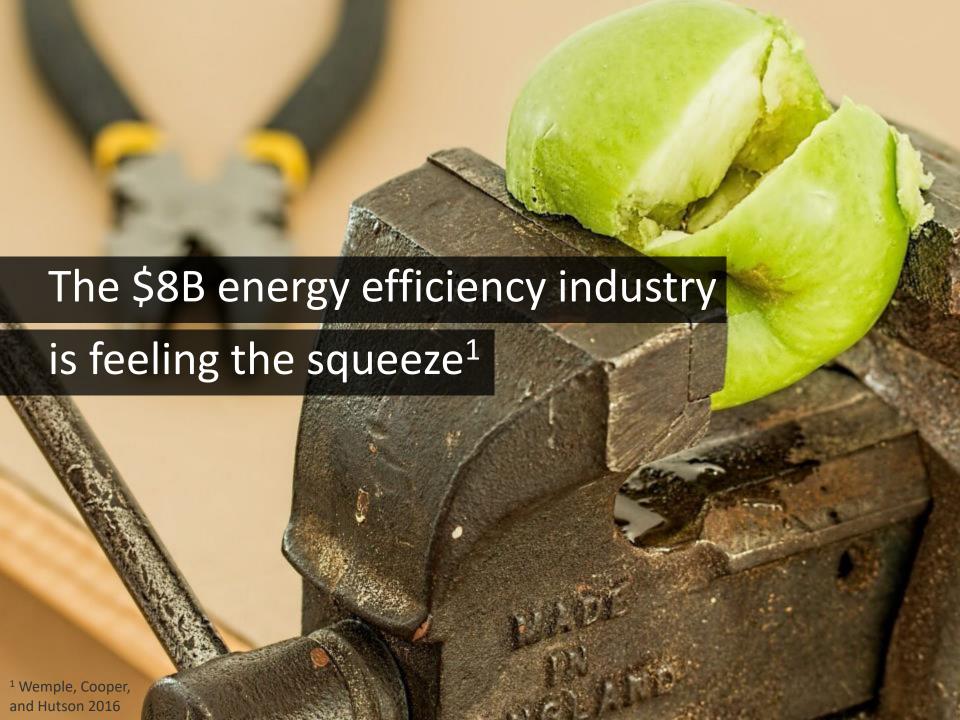
Eric Wilson
National Renewable Energy Laboratory

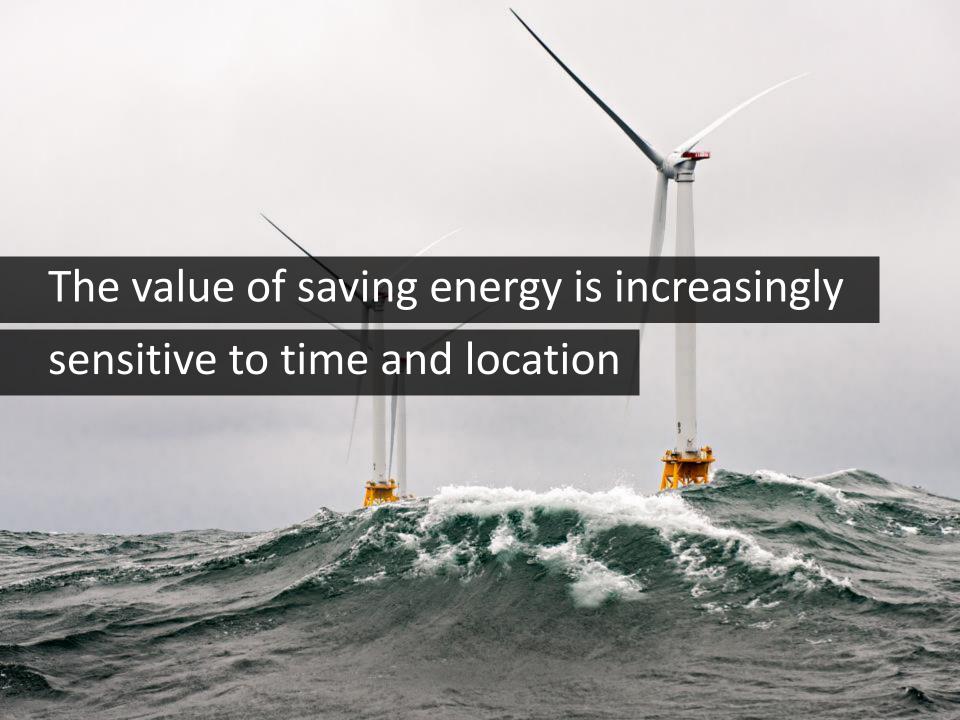




ResStock: Targeting Energy and Cost Savings for the U.S. Housing Stock

Eric Wilson
February 28, 2019
BBRN Webinar - We Love Our National Labs: Research Results



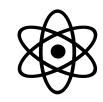








Housing stock characteristics database



Physics-based computer modeling



High-performance computing





Housing stock characteristics database

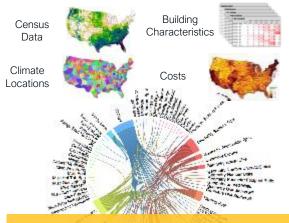


Physics-based computer modeling



High-performance computing

Large public and private datasets

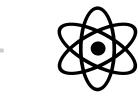


6000 probability distributions for 100 parameters structured in a dependency tree





Housing stock characteristics database

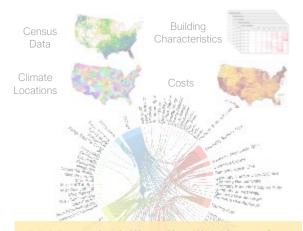


Physics-based computer modeling



High-performance computing

Large public and private datasets



6000 probability distributions for 100 parameters structured in a dependency tree

Best-in-class models



Detailed sub-hourly energy simulations







Housing stock



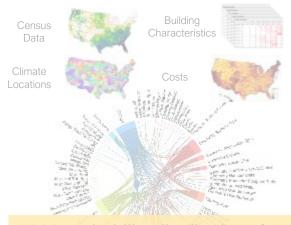


Physics-based



High-performance computing

Large public and private datasets



6000 probability distributions for 100 parameters structured in a dependency tree

Best-in-class models

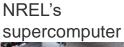




Detailed sub-hourly energy simulations



10,000s to 100,000s of simulations





Cloud computing



Big data technology stack









Payback, in years, for wall insulation retrofit in Washington and Oregon single-family homes

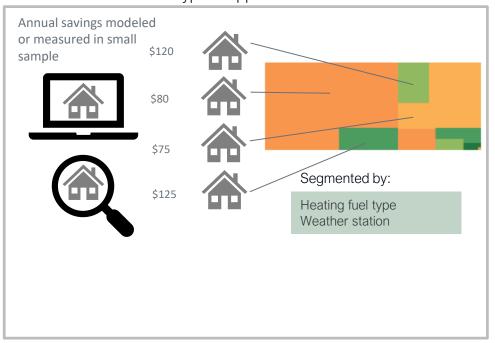
Typical Approach



Payback, in years, for wall insulation retrofit in Washington and Oregon single-family homes



Typical Approach



Payback, in years, for wall insulation retrofit in Washington and Oregon single-family homes



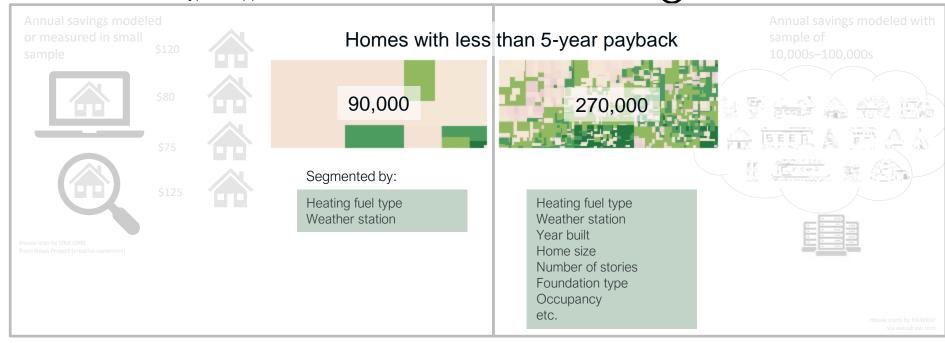
ResStock Typical Approach Annual savings modeled Annual savings modeled with sample of or measured in small \$120 sample 10,000s-100,000s \$80 \$75 Segmented by: \$125 Heating fuel type Heating fuel type Weather station Weather station Year built Home size Number of stories Foundation type Occupancy etc. House icons by HAWRAF via autodraw.com

Payback, in years, for wall insulation retrofit in Washington and Oregon single-family homes



Typical Approach





ResStock Applications



Utility companies and consultants

- Increase the cost-effectiveness of programs (\$8B/yr)
- Defer distribution infrastructure spending (\$20B/yr)



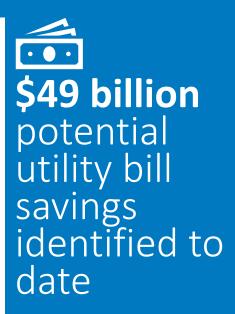
Manufacturers

- Prioritize R&D investments in emerging technologies
- **Identify target markets** to inform marketing and sales



Cities/States

- Identify the highest priority housing stock improvements
- Understand how buildings contribute to city/state energy or emissions targets



How is ResStock being used?

Example Applications



Radiant Labs

Start-up developing dashboard/targeting tool for cities

San Francisco, CA Burlington, VT Boulder, CO



XeroHome

Start-up developing homeowner-facing dashboard for utilities

SMUD, SCE pilots underway



Tendril

Estimating electric load flexibility for utility clients

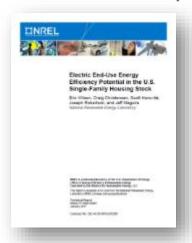


Los Angeles

ResStock is a key component of NRELled 100% renewable study for LA City Council and LADWP

Ways to benefit from ResStock

Read the Report



Energy Efficiency
Potential in the
U.S. SingleFamily Housing
Stock

Download State Factsheets



Explore Results



Interactive Data Viewer

Analyze Your Scenario BETA



Work with NREL or other trained consultants to analyze your scenario

Visit resstock.nrel.gov to get started

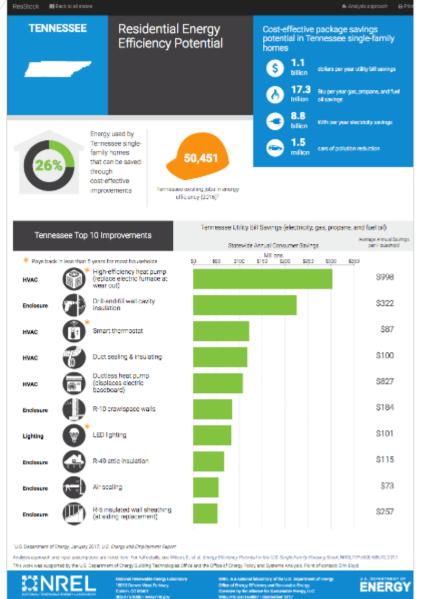
48 State Factsheets

Available at resstock.nrel.gov

State Fact Sheets

Click on a state to view a summary of the cost-effective residential savings potential and top priority improvements in that state.



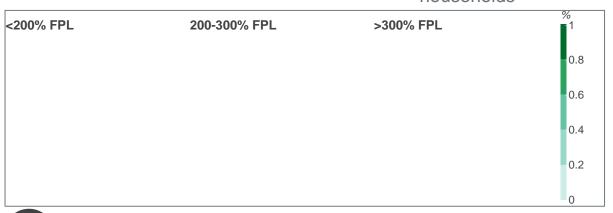


Application: Low-income EE potential

Low-income households

Moderate-income households

Highincome households



Percentage savings =

cost savings from NPV>0 upgrades total energy costs for single-family homes in the county and income bin



Central air conditioners upgraded to SEER 18 units at wear out (upgrades with positive net present value only)

<200% FPL	200-300% FPL	>300% FPL	% 0 .04
			0.035
			0.03
			0.025
			0.02
			0.015
			0.01
			0.005
			0

Reference:

Wilson et al. 2019
"Evaluating energy efficiency potential in low-income households: A flexible and granular approach"

Journal of Energy Policy (accepted)



Room air conditioners upgraded to ENERGY STAR-qualified (SEER 12) units at wear out (upgrades with positive net present value only)

Acknowledgements and Applications

Market & research partners



EERE Building Technologies Office EERE Office of Strategic Programs Office of Policy Office of Electricity





Regions 8 & 10



















Academic research partners













Key Points

- ResStock is a tool which allows for highly granular analysis of national, regional and local housing stocks.
- It leverages a database of housing stock characteristics, physics-based computer modeling and high-performance computing.
- \$49 billion in potential utility savings have been identified to date using ResStock.

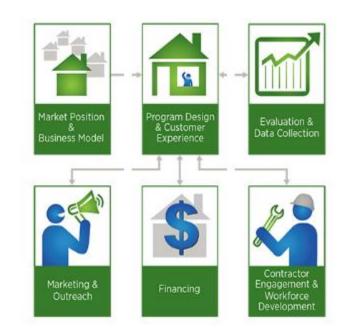




Explore the Residential Program Solution Center

Resources to help improve your program and reach energy efficiency targets:

- Handbooks explain why and how to implement specific stages of a program.
- Quick Answers provide answers and resources for common questions.
- Proven Practices posts include lessons learned, examples, and helpful tips from successful programs.
- Technology Solutions NEW! present resources on advanced technologies, HVAC & Heat Pump Water Heaters, including installation guidance, marketing strategies, & potential savings.



https://rpsc.energy.gov





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